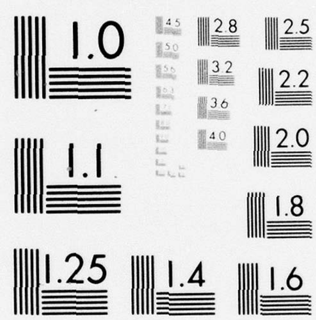
AD-A042 882 NAVAL RESEARCH LAB WASHINGTON D C F/G 4/1
IONOSPHERIC HOLES AND EQUATORIAL SPREAD-F: CHEMISTRY AND TRANSP--ETC(U)
JUL 77 E P SZUSZCZEWICZ

UNCLASSIFIED NRL-MR-3554 NL

1 OF 1
ADA042882

END
DATE
FILMED
9-77
DDC



(12)

NRL Memorandum Report 3554

Ionospheric Holes and Equatorial Spread-F: Chemistry and Transport

EDWARD P. SZUSZCZEWICZ

Upper Air Physics Branch
Space Science Division

July 1977

NAVAL RESEARCH LABORATORY
Washington, D.C.

(14) NRL-MR-3554

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Memorandum Report 3554	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) IONOSPHERIC HOLES AND EQUATORIAL SPREAD-F: CHEMISTRY AND TRANSPORT,		5. TYPE OF REPORT & PERIOD COVERED Interim report on a continuing NRL problem.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Edward P. Szuszczewicz		8. CONTRACT OR GRANT NUMBER(s) DNA Contract Number NWET L25AAXHX633
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D.C. 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NRL Problem A02-31
11. CONTROLLING OFFICE NAME AND ADDRESS (9) Memorandum Rept.,		12. REPORT DATE (11) July 1977
		13. NUMBER OF PAGES (12) 32 p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ionosphere
Spread-F
Communication effects
Ion chemistry
Ionospheric holes

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Existing experimental and theoretical results are synthesized with new ion mass spectrometer results from Atmosphere Explorer-C to provide a more comprehensive perspective on the understanding of nighttime equatorial irregularities. Particular attention is given to possible relationships between ionospheric holes and smaller scale (3 meter) irregularities observed by ground-based radar. From chemistry and transport it is argued that equatorial holes and equatorial spread-F can be one and the same phenomenon, with the smaller scale irregularities imbedded within the much larger scale ionospheric depletions.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

251950

CONTENTS

IONOSPHERIC HOLES AND EQUATORIAL SPREAD-F: CHEMISTRY AND TRANSPORT

I. Introduction

Accumulating information regarding the nighttime equatorial ionosphere has shown it to be a very exciting and relevant region for scientific investigation. For more than twenty-years radio astronomers have known that the nighttime equatorial ionosphere could at times seriously degrade radio star signals as they passed through the near-Earth charged particle environment to ground-based radio telescopes. More recently, transionospheric communication systems have found themselves plagued by the same perturbation.

It was generally agreed that spatial and/or temporal fluctuations in ionospheric electron densities were the cause for the transionospheric scintillation phenomena but accumulating statistics only provided morphological models with geographic and temporal probabilities for occurrance. This information, while valuable in defining the problem in space and time, provided little information on the fundamental cause-effect relationships between zero-order geophysical plasma conditions, the ionospheric irregularities, and observed scintillation phenomena.

Note: Manuscript submitted June 30, 1977.

In recent years, considerable advances have been made, largely as a result of improved "in-situ" measurement techniques, expanded and detailed ground-based radar observations, and the development of computational techniques that describe candidate plasma instabilities that might be active in the nighttime equatorial ionosphere. The end result has been a rapidly improved understanding of the active physical principles brought about by a conscious and dynamic interaction between theory and experiment.

The interest and increased activity in the study of the equatorial ionosphere has resulted in modifications in theoretical models as new and improved data is made available. As yet there is no completely satisfactory explanation for the cause, development, chemistry, and transport of irregularities in the nighttime equatorial ionosphere. Even the long-standing morphology of equatorial irregularities has been scrutinized, raising questions of previously unrecognized longitudinal dependencies.

A schematic presentation of equatorial irregularities is shown in Fig. 1 which portrays the ionosphere at 350 km in the noon-midnight meridian. Considerable licence has been employed in constructing this Figure but it is sufficiently accurate for purposes of discussing statistical and morphological results. The data base

[Balsley et al. [1972], Dyson et al. [1974], Hanson et al. [1973 a, b], Farley, [1974], Kelley and Mozer, [1976], McClure and Woodman [1972], McClure and Hanson [1973]] (including scintillation observations [Aarons and Allen [1970], Koster [1972]) indicates that ionospheric irregularities have latitudinal, diurnal, seasonal, and solar-cycle variations with day-to-day perturbations superimposed. Spread-F is essentially a nighttime phenomenon in the equatorial region ($\pm 20^{o}$ of the magnetic dip equator) with the most intense periods of irregularities occuring within (2200±3) hr LT. It appeared that the majority of irregularities fell into the "noiselike" structure where the amplitude of such irregularities increases approximately as the irregularity scale size. More recently however, the work of Brinton et al [1975] indicates that the "bite-outs" reported by Hanson and Sanatani [1973a], and McClure and Hanson [1973] occur more frequently than originally thought, and in fact are considered just as characteristic of spread-F as the less intense irregularities.

Typically, the ion composition is vastly different inside and outside the "bite-outs". Fe^{+} ions may be enhanced or depleted, with molecular ions usually more abundant inside the bite-out. Brinton et al. [1975] have found O^{+} depleted by as much as a factor of 10^{3} to a concentration below that of NO^{+}. The molecular ion NO^{+}

was found to be the dominant ion in the O^+ depleted region and it was found that the bite-outs varied from a few kilometers to tens of kilometers in width.

These observations suggest that any study of equatorial irregularities must determine the degree of balance between the chemistry and the dynamics of the ionosphere. In the case of chemistry, the electron energy plays a critical role in the dissociative and radiative recombination of N_2^+, O_2^+, NO^+, O^+, and Fe^+. For radiative recombination of O^+, the rate varies as $T_e^{-1.5}$ for Maxwellian electrons in transitions involving higher energy levels [Biondi, 1972]; while dissociative recombination of molecular ions depends on $T_e^{-1.0}$ [Torr et al, 1976; Oppenheimer and Brace, 1976]. The chemical balance is particularly sensitive to the inverse power law dependence on T_e because the electron gas can be heated by as much as a factor of two in the bite-outs. The heating can result from reduced collisional cooling in the presence of a depleted ion population [Bernhardt, 1976].

The impact of T_e on chemistry, coupled with the fact that T_e controls the short wavelength cutoff in the linear development of ionospheric fluid-type plasma instabilities [Ossakow, 1974] establishes the measurement of electron temperature as important to a full understanding of spread-F irregularities and equatorial bite-outs.

For comparative purposes Figure 1 includes higher latitude morphology to illustrate that active phenomena at equatorial and high latitude sites are fundamentally different as a result of major differences in the geomagnetic field. At high latitudes where geomagnetic field lines intercept the earth, charged particles of solar origin can readily penetrate to ionospheric levels, interact with neutral and ionized species and produce irregularities which to large measure can be correlated with particle precipitation patterns. The mid-latitude ionosphere is normally smooth but the poleward edge of the nighttime mid-latitude trough is almost always associated with the onset of auroral electron fluxes and larger percentage amplitude irregularities than generally observed in the equatorial region. Since scintillation effects vary directly with the absolute magnitude of electron density fluctuations, one finds stronger scintillations in the equatorial region where F-region electron densities are generally larger than at high latitude sites. These morphological comparisons apply to the "noiselike" irregularities which are common to equatorial and high-latitude sites; as yet there have been no observations of a high-latitude counterpart to the equatorial bite-outs.

In the sections which follow, existing radar, rocket, satellite, and theoretical results will be synthesized to provide a more comprehensive perspective on the understanding of nighttime equatorial irregularities. Particular

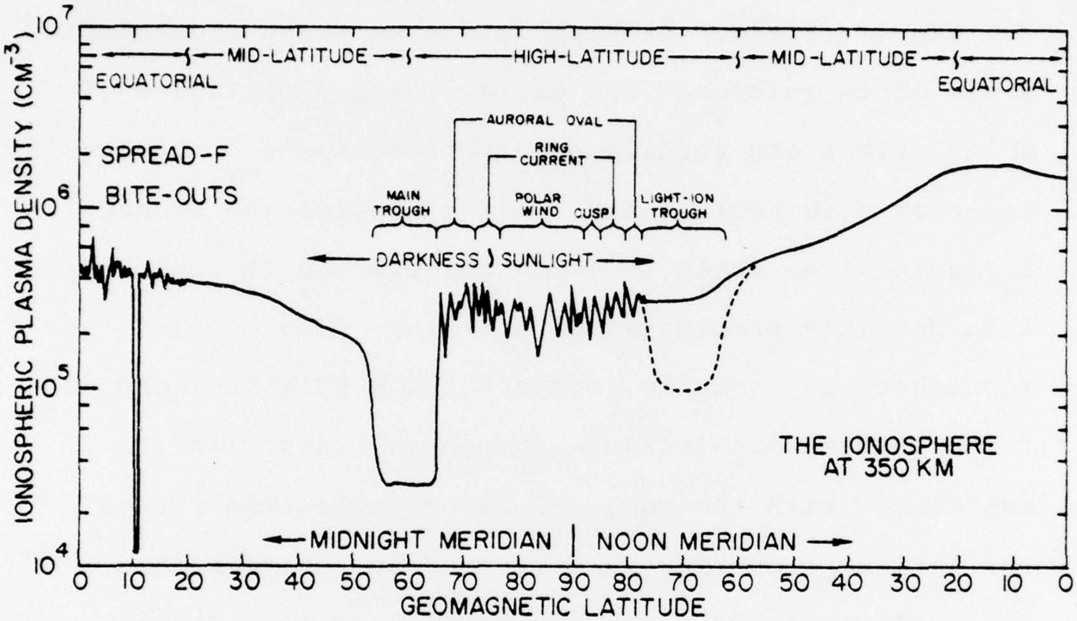


Fig. 1 — Schematic presentation of F-region irregularities at 350 km in the noon-midnight meridian

attention will be given to the possible relationship between ionospheric bite-outs and the smaller scale (down to 3 meter) irregularities observed by ground-based radar. It will be argued that bite-outs and spread-F can be one and the same phenomenon with the smaller scale irregularities imbedded within the much larger scale ionospheric depletions. It will also be argued that the observed chemical composition within the regions of irregularities can be utilized as signatures or tracers of their spatial origin and their time of transport.

II. Three-Meter Observations of Spread-F

The Jicamarca Observatory (75^{o}W, 11^{o}S; 0.2^{o} dip) near Lima, Peru has provided the most extensive data base for the time and space development of equatorial spread-F. Operating at 50 MHz, the Observatory's radar shows reflections from 3 meter size ionospheric irregularities as a function of altitude and time. Figure 2 shows a typical RTI (Range-Time-Intensity) plot collected in the evening during spread-F conditions. The abscissa is time, increasing from early evening on the left to the early morning hours on the right. The figure is used here to summarize some of the more salient features of the radar observations that will be coupled to subsequent discussions on chemistry and transport. More

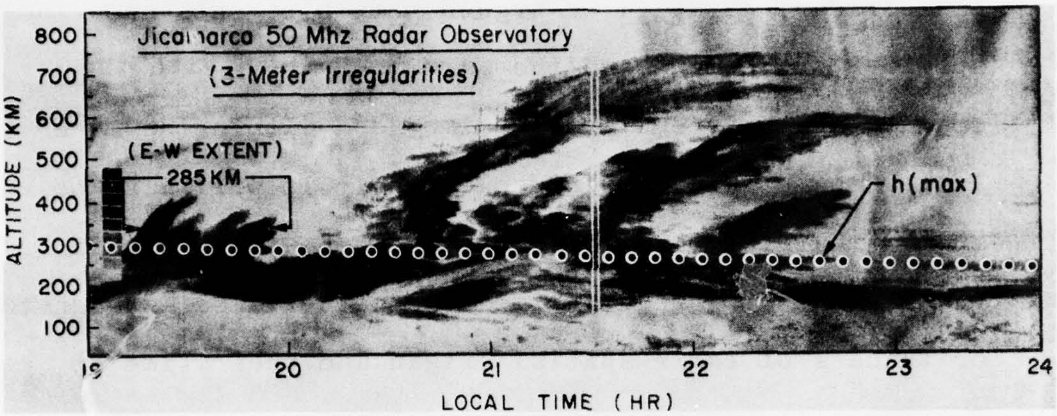


Fig. 2 — Range-time-intensity (RTI) plot of backscatter energy at Jicamarca Observatory. Superimposed is the nominal location of the F-layer peak.

detailed discussions and reviews of RTI data base at Jicamarca is available in the work of Woodman and La Hoz [1976].

The gray-scale shows intensity of radar energy reflected from 3 meter scale size irregularities...the darker the image, the greater the reflected energy. The dotted line on the RTI plot locates the nominal altitude of the F-layer peak (h(max)). The h(max) line is not the result of actual data collected simultaneously with the RTI plot but represents accumulated information on the post-sunset behavior of the laminar ionosphere over Jicamarca (See e.g., Farley, et al [1967], and Calderon [1975]).

The salient features in Figure 2 are as follows:

(a) Three-meter size irregularities are fundamentally a bottom-side Spread-F condition in the early evening hours.

(b) The irregularities tend to rise-up and break-away from their lower altitude source region. This observation has spawned the use of the terms "bubbles", "plumes", and "fingers" to describe the motion of the irregularity domains.

(c) The irregularities that break away generally move upward, with their intensity generally decreasing as time moves into the early morning hours.

(d) Bottom-side irregularities generally persist throughout the entire period of spread-F conditions. This is not the case for top-side irregularities.

Additional conclusions can be drawn from Woodman and La Hoz [1976] concerning the relationship between the time axis of the RTI plot and the East-West profile of irregularity structure. They note that since the ionospheric plasma superrotates in an easterly direction at an approximate rate of 125 m/sec, a one hour excursion in time on an RTI plot is equivalent to a 450 km E-W separation. With some qualifications imposed by temporal F-region developments, one can therefore view one-hour segments of any RTI plot as an approximate E-W snapshot of regions of 3 meter size irregularities as one looks toward the south. This observation suggests the following conclusions:

(i) The three-meter size irregularities generated on the bottom-side tend to move upward and westward; and

(ii) The east-west extent of the topside irregularity regions are extremely variable with time and altitude. Consider in Fig. 2 the early evening horizontal cut at an altitude of 340 km. A properly instrumented satellite passing through this region would observe three meter size irregularities over a 285 km range with sub-structure down to approximately 10 km.

III. Larger-Scale Irregularities: Ionospheric Holes

The ability of the radar technique to determine the space-time development of spread-F has contributed a great deal to our current understanding. But it must be recognized that the 50 MHz system at Jicamarca presents almost no information about irregularity structures other than those at 3 meter size. Additionally, the radar cannot provide details on the chemistry which might play a vital role as a cause, an effect, or a tracer for conditions leading up to or stemming from the onset of spread-F. In this section, arguments will be presented which lead to relationships between 3 meter scale size irregularities and larger scale (up to tens of kilometers) depletions referred to in the literature as ionospheric bite-outs or holes.

To describe recent chemical information on bite-outs, some of the AE-C Bennett Ion Mass Spectrometer(BIMS) observations of Brinton, et al [1973 and 1975] are presented. General characteristics of those observations at equatorial latitudes are shown in the data sample of Fig. 3 where the densities for O^+, O_2^+, and NO^+ are shown in one crossing as the satellite traverses the equatorial region in a slightly eccentric (260 X 280 km) orbit. The following features in Fig. 3 are to be noted:

(a) There are regions of major ionospheric plasma depletions ("holes") which vary in width from approximately 2^o (~ 225 km) to 25^o (~ $3(10^3)$ km) in latitude where the O^+ concentration drops by as much as a factor of 10^3 to a level below that of NO^+.

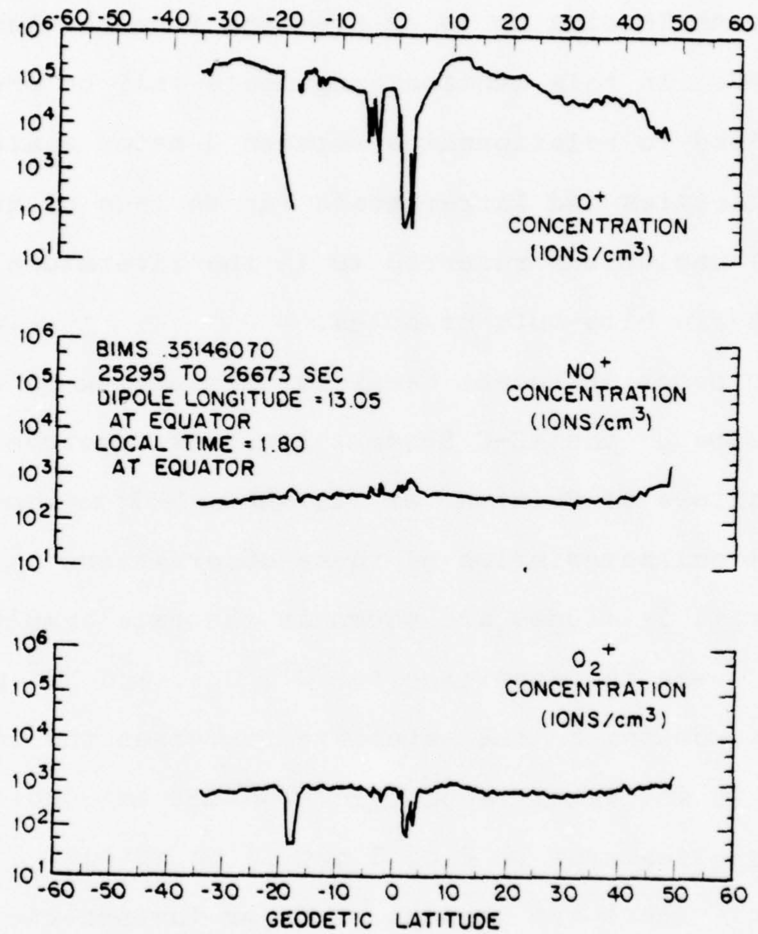


Fig. 3 — AE-C Bennett Ion Mass Spectrometer (BIMS) measurements of O^+, $O_2{}^+$, and NO^+ in a single equatorial crossing near 265 km

(b) Outside the holes, O^+ is the dominant atomic and O_2^+ is the dominant molecular; O_2^+ is observed to decrease with O^+ in the depleted regions and NO^+ becomes the dominant ion.

(c) NO^+ is observed to vary inversely with O_2^+. (It's important to note that data collected at lower altitudes [Brinton, et al 1975] at times show O^+, O_2^+, and NO^+ all decreasing within the holes.)

In order to investigate what appears in this data to be a rather complex balance between chemistry and transport, the active F-region chemistry must be outlined.

The primary source for plasma production at low-to-mid latitudes is photoionization of the neutral atmospheric constituents. This is true even in the nighttime ionosphere where resonantly scattered ultraviolet radiation can play a substantial role [Strobel, et al 1974]. Consequently the source mechanisms in a simple three component neutral atmosphere (N_2, O_2, O) proceeds according to the reactions

$$N_2 + h\nu \xrightarrow{k_1} N_2^+ + e^- \tag{1}$$

$$O_2 + h\nu \xrightarrow{k_2} O_2^+ + e^- \tag{2}$$

and

$$O + h\nu \xrightarrow{k_3} O^+ + e^- \tag{3}$$

where the production rates depend on the wavelength and flux of the impinging ionizing radiation, the atmospheric constituent in question, and the local neutral gas concentration and mass distribution.

In the lower thermosphere the nitric oxide ion NO^+ is the major ionic species, produced by chemical reactions with the other constituents. Down to altitude of 155 km the major sources of NO^+ [Oppenheimer et al, 1977] involve the reactions

$$O^+ + N_2 \xrightarrow{k_4} NO^+ + N \quad (4)$$

$$N_2^+ + O \xrightarrow{k_5} NO^+ + N \quad (5)$$

with the only significant loss mechanisms being dissociative recombination in accordance with

$$NO^+ + e^- \xrightarrow{k_6} N + O \quad (6)$$

Under steady state conditions the density of NO^+ is given by

$$[NO^+] = \frac{k_4[O^+][N_2] + k_5[N_2^+][O]}{k_6 N_e} \quad (7a)$$

Ignoring the second term in accordance with the analysis of Torr, et al [1967], and selecting

$k_4 = 6(10^{-13})\ cm^3 sec^{-1}$ [Lindiger et al, 1974], and

$k_6 = 4.2(10^{-7})(300/T_e)$ [Torr et al, 1976]

we can write

$$[NO^+] = 4.8(10^{-9})\frac{[O^+][N_2]}{N_e} T_e \quad . \qquad (7b)$$

Plasma loss mechanisms for the other ionic components are radiative and dissociative recombination with the latter preceeding at a rate approximately 10^5 times faster than the former. Consequently, the loss of O^+ occurs in a two step process involving charge exchange with a neutral molecular,

$$O^+ + O_2 \xrightarrow{k_8} O_2^+ + O \qquad (8)$$

$$O^+ + N_2 \xrightarrow{k_9} NO^+ + N, \qquad (9)$$

followed by dissociative recombination of the resulting ion with an ambient electron in accordance with reaction(6) as well as with

$$O_2^+ + e^- \xrightarrow{k_{10}} O + O \quad . \qquad (10)$$

The chemical loss mechanisms for the F-region ionosphere are completed in this simple model by including the reaction

$$N_2^+ + e^- \xrightarrow{k_{11}} N + N \quad . \qquad (11)$$

The rates associated with reactions (8) through (11) are

$$k_8 \equiv \gamma(O_2) = 2.0(10^{-11})\left(\frac{300}{T_e}\right)^{1/2} \text{cm sec}^{-1} \quad \text{[Dunkin et al.1968]} \qquad (12a)$$

$$k_9 = k_4 \equiv \gamma(N_2) = 6(10^{-3})\ \text{cm}^3\,\text{sec}^{-1} \quad \text{[Dunkin et al.1968]} \qquad (12b)$$

$$k_{10} \equiv \alpha(O_2{}^+) = 2.2(10^{-7})\left(\frac{300}{T_e}\right)^{0.7} \text{cm}^3\,\text{sec}^{-1} \quad \text{[Biondi,1969]} \qquad (12c)$$

$$k_{11} \equiv \alpha(N_2{}^+) = 3.4(10^{-7})\left(\frac{300}{T_e}\right)^{0.39} \text{cm}^3\,\text{sec}^{-1} \quad \text{[Biondi,1969]} \qquad (12d)$$

Under certain circumstances plasma fluxes can play an important role in the overall chemical balance. For example, an additional O^+ source can result from a downward diffusion of H^+ into F-region altitudes where monoatomic oxygen is abundant. Under these conditions the oxygen atom may undergo charge exchange in accordance with the reaction

$$H^+ + O \underset{}{\overset{k_{13}}{\rightleftarrows}} O^+ + H \qquad (13)$$

where $\overrightarrow{k_{13}} = 2.4\ (10^{-11})\ T_i^{1/2}\ \text{cm}^3\,\text{sec}^{-1}$ (14a)

and $\overleftarrow{k_{13}} = 3.9\ (10^{-11})\ T_n^{1/2}\ \text{sec}^{-1}$ [Fehsenfeld and Fergusen, 1972] (14b)

The direction of plasma flow has diurnal dependence with H^+ flowing downward at night and O^+ flowing up-upward in the day. The O^+ that diffuses upward converts to H^+ in accordance with the rate in reaction (13).

With the F-region chemistry as a background, some insight into the dichotomous behavior of $[NO^+]$ relevant to $[O^+]$ depletions as discussed in the BIMS data can be gained by writing Eq. (7b) as

$$[NO^+] = \frac{4.8(10^{-9})\ T_e[O^+][N_2]}{[O^+] + [O_2{}^+] + [NO^+]} \tag{15a}$$

with a rearrangement of terms yielding

$$[NO^+]^2 + ([O^+] + [O_2{}^+])\ [NO^+] - 4.8(10^{-9})[O^+][N_2]T_e = 0. \tag{15b}$$

Taking a total derivative, and algebraically manipulating the terms leads to

$$\frac{d[NO^+]}{d[O^+]}\left(2\ [NO^+] + [O^+] + [O_2{}^+]\right) =$$

$$4.8(10^{-9})\ T_e\ [N_2] - [NO^+]\ .\left(1 + \frac{d[O_2{}^+]}{d[O^+]}\right) \tag{16}$$

when $\quad [N_2] >> [O^+]\ \dfrac{d[N_2]}{d[O^+]} \quad .$ (17)

From Eq. (16) we can conclude that

$$\frac{d[NO^+]}{d[O^+]} \gtrless 0 \tag{18}$$

when $\quad 4.8(10^{-9})\ T_e\ [N_2] \gtrless [NO^+]\left(1 + \dfrac{d[O_2{}^+]}{d[O^+]}\right) \quad ,$ (19)

a condition which can be approximated by

$$4.8(10^{-9})\ T_e \gtrless \frac{[NO^+]}{[N_2]} \tag{20}$$

in deep O^+ bite-outs where the BIMS data shows that $d[O_2{}^+]\ /d\ [O^+] << 1$.

Qualitatively, the latter expression indicates that at lower altitudes where $[N_2]$ is greater, conditions favor

$$4.8(10^{-9})\sqrt{T_e} > [NO^+]/[N_2]$$

so that

$$d[NO^+]/d[O^+] > 0 \qquad (21)$$

On the other hand, higher altitudes and reduced $[N_2]$ densities favor

$$4.8(10^{-9})\sqrt{T_e} < 10^2[NO^+]/[N_2]$$

so that

$$d[NO^+]/d[O^+] < 0 \qquad (22)$$

The relationships shown in (21) and (22) are exactly those reported by Brinton et al [1975] in their low and high altitude observations, respectively.

In an effort to quantify this discussion we note that the BIMS observations of NO^+ were always in the range $[NO^+] \lesssim 2(10^3)\,cm^{-3}$. Comparing this maximum $[NO^+]$ value with CIRA 1972 values for N_2 at a 900°K exospheric temperature, we find

$$\frac{[NO^+]}{[N_2]} \approx 8(10^{-8}),\ 1(10^{-6}),\ 6(10^{-6})$$

at 150 km, 200 km, and 250 km, respectively. With T_e = 1000°K, the left side of (20) becomes $4.8(10^{-6})$, indicating that the transition for (20) is in the 200-250 km region. This result finds itself in relatively good agreement with the BIMS observations.

More important than the $[NO^+]$ behavior is the actual cause for the major O^+ depletions. If the cause involved local chemistry, the observations must necessarily be explicable in terms of Eqs. (3), (8), and (9) which together yield

$$[O^+] = \frac{k_3 I(h\nu)}{k_8[O_2]+k_9[N_2]} \quad . \tag{23}$$

If local chemistry were in fact responsible for the $[O^+]$ depletion then only major fluctuations (orders of magnitude) in neutral densities could be responsible. This is difficult to justify. It is suggested that a more likely mechanism is one which involves the transport of a given ionospheric plasma volume from one region of the ionosphere where moleculars dominate to a region where atomic ions are the principal species. This is exactly the type of transport indicated in the 3 meter scale size radar observations of spread-F. The "bubbles" originate on the bottom side of the F-layer in the presence of molecular ion domination and move upward in the ionosphere to higher altitudes where O^+ is the dominant species.

IV. Additional Comments and Comparisons

Very recently, McClure et al [1977] have reported Atmosphere Explorer satellite measurements of ionospheric bite-outs associated with smaller-scale structure down to a km. Some, but not all of the bite-outs moved upward, and those moving upward typically were found to move westward with respect to the background plasma. From their measurements they conclude that the upward moving bite-outs have the lower ionosphere as their source region. This parallels the discussion in the previous Section and agrees with the computational work of Scannapieco and Ossakow (1976) which showed that bottom-side F-region irregularities at low plasma densities (10^2-$10^4 cm^{-3}$) could be transported to more dense ionospheric domains (10^5-$10^6 cm^{-3}$) and appear as ionospheric holes. This source region can be low enough in the ionosphere to encompass domains of molecular ion domination but cannot be so low as to damp the growth of plasma instabilities necessary to raise it to higher altitudes (Ossakow, private communication).

The model which now emerges is one which allows a given chemical volume on the bottom side F-layer ($[NO^+], [O_2^+] > [O^+]$) to move upward through a stationary neutral atmosphere and appear at higher altitudes as a "bite-out" in the local plasma density. As this plasma cell moves upward the relative magnitudes of its ionic components depend on altitude through the height distribution of the neutral gases. This is exactly the situation which explained in the previous section the apparent dichotomous BIMS observation of $[NO^+]$ in ionospheric bite-outs.

Another view of this model is illustrated in Fig. 4 which depicts the electric potentials and fields that are necessarily associated with the electron density gradients that exist across the walls of the bite-out. These fields are so directed as to confine the molecular ions within the cell and to maintain the initial chemical state as the cell moves upward in the F-region ionosphere. As depicted, the electric fields would also tend to fill the cell with O^+ ions from the outside unless plasma turbulence generated across the steep density gradients inhibited the inward flow of O^+. This turbulence might also be a source of 3 m radar backscatter measured by the Jicamarca Observatory.

It is appropriate to note that some apparent bite-outs might simply be the observation of an F-layer tilt. There is accumulating information that there can be significant longitudinal variations in the height of the F-layer peak. A satellite making observations near the peak of the F-layer may "ride" up and down the bottom side gradient as it moves along its orbital track. This would appear as a major depletion in O^+ with a dominance of molecular ions in the "hole".

The arguments developed here, showing a parallel between large scale ionospheric bite-outs and 3-meter size irregularities normally identified with ionospheric

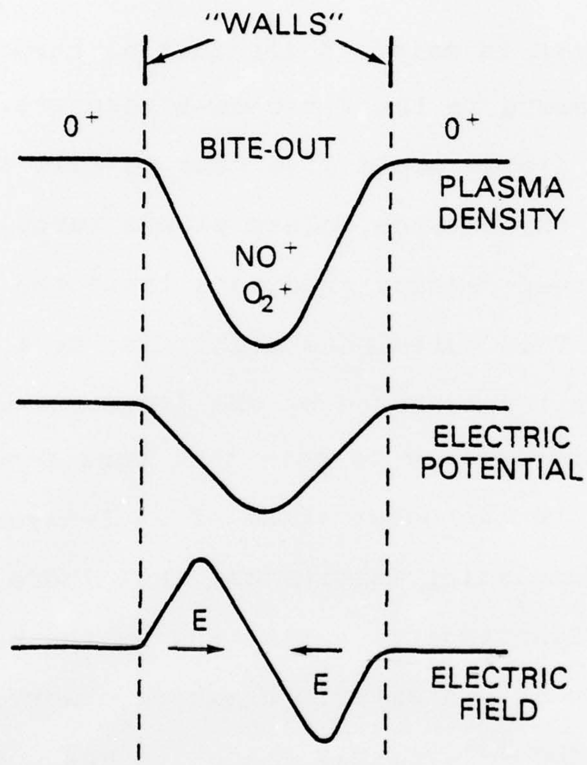


Fig. 4 — A simplistic view of an ionospheric hole and its associated electric fields

spread F, can also be viewed as consistent with earlier observation of Fe^+ at high equatorial altitudes. But the picture here is broader in scope, indicating that NO^+ and O_2^+ are more likely to be consistent signatures of spread-F since they are characteristic of bottom-side composition which is maintained in first order as it is transported to the top-side. The existence of Fe^+ on the top side is likely to be dependent on a two step process which first requires the transport of metallic ions from the 95 km region to the bottom side of the F-layer as a result of the strong polarization fields which accompany the equatorial electrojet. The continued upward movement of Fe^+ can then be a manifestation of the "fountain effect" as described by Hanson, et al. (1972) or a further demonstration of transporting a "frozen" chemical volume of bottom side composition to higher altitudes by the Rayleigh-Taylor process. In this case O^+ will always be depleted, while the moleculars NO^+ and O_2^+ dominate; and Fe^+ will be present only when the E-region transport mechanism is actively depositing Fe^+ on the bottom-side of the F-region. As the "frozen" chemical volume moves upward in a stationary background ionosphere $d[NO^+]/d[O^+]$ changes from a negative to positive relationship near the 250 km region.

V. SUMMARY

Nighttime equatorial F-region irregularities have been compared from two points of view: small scale turbulence (3-meter size) and the much larger scale phenomena (km size) referred to as ionospheric holes and bite-outs. The following similarities emerge from the study:

(1) Holes and 3-m F-region irregularities are nighttime equatorial phenomena with no high-latitude counterparts. The macrostructure of the 3-m domains is comparable to that of the ionospheric holes.

(2) In general, both types of irregularities originate on the bottom-side of the F-region peak. This is clearly documented for 3-m irregularities in the time development studies available in radar RTI plots· but at present only plausibility arguments can be advanced for the bottom-side F-region as the source of holes observed at higher altitudes. The BIMS ion composition data discussed here supports the premise that a molecular-ion-dominated plasma volume on the bottom-side F-layer can move upward through a stationary neutral atmosphere and appear at higher altitudes as a hole in the locally, more dense plasma which is dominated by atomic oxygen ions.

(3) Because of limited resolution in current satellite instrument complements there is no experimental evidence that can show that the 3-m irregularities are directly associated

with the larger scale holes. However, theoretical arguments which require bottom-side F-region density gradients to support the Rayleigh-Taylor instability can also be applied to the density gradients that exist across the boundaries of the ionospheric holes. We therefore expect that 3-m turbulence can be generated in and around the holes and be observed by Jicamarca Radar as a plume which tracks one or more holes in its upward movement in the F-layer ionosphere.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. H. Brinton for many stimulating discussions of the BIMS measurements on AE-C and for his permission to use some of the data in this paper. Sincere thanks is also extended to Mr. C.Y. Johnson, and Drs. Strobel and Ossakow for their helpful suggestions in the review and development of this work which was supported in part by the Office of Naval Research and the Defense Nuclear Agency under Contract No. L25AAXHX633.

REFERENCES

Aarons, J., and R.S. Allen, "Scintillation boundary during quiet and disturbed magnetic conditions," J. Geophys. Res. 76, 170 (1971).

Balsley, B.B., G. Haerendel and R. A. Greenwald, "Equatorial spread F:Recent observations and a new interpretation", J. Geophys. Res. 77, 5625 (1972).

Basu, S., S. Basu, and B. K. Khan, "Model of equatorial scintillations from in-situ measurements," Radio Science (1976, submitted for publication).

Bernhardt, P.A., "Response of the ionosphere to the injection of chemically reactive vapors," Tech. Rpt. No. 17, Radio Science Laboratory, Stanford Electronics Laboratories, Stanford Unniversity (May 1976).

Biondi, M.A., "Charged particle recombination processes," in Reaction Rate Handbook, DNA 1948H, p. 16-1, edited by M. H. Bortner and T. Baurer (DASIAC, GE TEMPO, Santa Barbara, CA, 1972).

Biondi, M.A., "Atmospheric electron-ion and ion-ion recombination processes," Can. J. Chem. 47, 1711 (1969).

Brinton, H.C., L.R. Scott, M.W. Pharo, III, and J.T. Coulson, "The Bennett ion mass spectrometer on Atmosphere Explorer-C and -E," Radio Sci. 8, 323 (1973).

Brinton, H. C., H.G. Mayr, and G.P. Newton, "Ion composition in the nighttime equatorial F-region: Implications for chemistry and dynamics," Trans. Am. Geophys. U. 56, 1038 (1975).

Calderon, C.H.J., "Report on coordinated satellite and incoherent scatter observations," Rpt. of the Instituto Geofisico del Peru, Radio Observatorio de Jicamarea (October 1975).

Dyson, P.L., J.P. McClure, and W.B. Hanson, "In site measurements of the spectral characteristics of F-region ionospheric irregularities," J. Geophys. Res. 79, 1497 (1974).

Farley, D.T., B.B. Balsley, R.F. Woodman, and J.P. McClure, "Equatorial spread F: Implications of VHF radar observations," J. Geophys. Res. 75, 7199 (1970).

Farley, D.T., "Irregularities in the equatorial ionosphere: The Berkner Symposium," Rev. Geophys. Space Phys. 12, 285 (1974).

Farley, D.T., J.P. McClure, D.L. Sterling, and J.L. Green, "Temperature and composition of the equatorial ionosphere," J. Geophys. Res. 72, 5837 (1967).

Fehsenfeld, F.C. and E.E. Ferguson, "Thermal energy reaction rate constants for H^+ and CO^+ with O and NO," J. Chem. Phys. 56, 3066 (1972).

Hanson, W.B., and S. Sanatani, "Large N_i gradients below the equatorial F-peak," J. Geophys. Res. 78, 1167 (1973a).

Hanson, W.B., D.L. Sterling, and R.F. Woodman, "Source and identification of heavy ions in the equatorial F layer," J. Geophys. Res. 77, 5530 (1972).

Hanson, W.B., J. P. McClure, and D.L. Sterling, "On the cause of equatorial spread-F," J. Geophys. Res. 78, 2353 (1973b).

Hudson, M.K., and C.F. Kennel, "Linear theory of equatorial spread F," J. Geophys. Res. 80, 4581 (1975).

Kelley, M.C., and F.S. Mozer, "A review of the recent results of in-situ ionospheric irregularity measurements and their relation to electrostatic instabilities," in Effects of the Ionosphere on Space Systems and Communications, J. M. Goodman ed., (Gov't. Printing Office, Wash., DC), 1976.

Koster, J.R., "Equatorial scintillation," Planet. Space Sci. 20, 1999 (1972).

Lindinger, N.F.C., Fehsenfeld, A.L., Schmeltekopf, and E.E. Ferguson, "Temperature dependence of some ionospheric ion-neutral reactions from 300^o-900^oK, J. Geophys. Res. 79, 4753 (1974).

McClure, J.P., and R.F. Woodman, "Radar observations of equatorial spread-F in a region of electrostatic turbulence," J. Geophys. Res. 77, 5617 (1972).

McClure, J.P., and W.B. Hanson, "A catalog of ionospheric F region irregularity behavior based on OGO-6 retarding potential analyzer data," J. Geophys. Res. 78, 7431 (1973).

McClure, J.P., W.B. Hanson, and J.H. Hoffman, "Plasma bubbles and irregularities in the equatorial ionosphere," J. Geophys. Res. (1977, in press).

Oppenheimer, M., A. Dalgarno, F.P. Trebino, L.H. Brace, H.C. Brinton, and J.H. Hoffman, "Daytime Chemistry of NO^+ from Atmospheric Explorer-C Measurements," J. Geophys. Res. 82, 191 (1977).

Oppenheimer, M and L. Brace, "Recombination rate coefficient of NO^+ from thermosphere daytime chemistry," Trans. Am. Geophys. U. 57, 297, (1976).

Ossakow, S.L., "Research at NRL on theoretical and numerical simulation studies of ionospheric irregularities." NRL Memo Rpt. 2907 (Oct. 1974).

Scannapieco, A.J. and S.L. Ossakow, "Nonlinear equatorial spread F," Geophys Res. L. 8, 451 (1976).

Strobel, D.F., T.R. Young, R.R. Meier, T.P. Coffey, and A.W. Ali, "The nighttime ionosphere: E region and lower F-region," J. Geophys. Res. 79, 3171 (1974).

Torr, D.G., M.R. Torr, J.C.G. Walker, L.H. Brace, H.C. Brinton, W.B. Hanson, J.H. Hoffman, A.O. Nier, and M. Oppenheimer, "Recombination of NO^+ in the ionosphere," Geophys Res. L. 3, 209 (1976).

Woodman, R.F., and C. LaHoz, "Radar observations of F-region equatorial irregularities," J. Geophys. Res. 81, 5447 (1976).